GE Transportation
Aircraft Engines

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Carol Horgan
Powerplants Group Chairperson
National Transportation Safety Board

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Dear Ms Horgan:

The attached document, entitled *CF34 "Core Lock,"* was created specifically to respond to requests from the NTSB. On December 2, 2004, GE provided the document to the NTSB for the purpose of assisting the NTSB in the DCA05MA003 investigation. The document has been called a "white paper" in that it is a summary of GE's understanding on the questions raised by the NTSB.

The *CF34 "Core Lock"* document focuses on GE's understanding and history of the core lock condition in the context of Bombardier's production acceptance flight test ("FTP") testing. As such, the theory and physics addressed in the document relate to FTP conditions and experience at low power engine operation. Similarly, the focus on the role of the inter-stage seal (ISS) in core lock events reflects the FTP experience. The description of the core lock condition in this paper is based upon our engineering knowledge, assumptions, and experience as of December 2, 2004.

The history of design changes described in the white paper reflects GE's understanding as of December 2, 2004, and had not been subjected to extensive documentation auditing. GE continues to study additional design changes and further evaluation of whether those changes had an influence on the core lock condition.

The description of GE's experience with "hot engine" or higher power shutdowns includes event experience beyond the FTP testing because the NTSB asked GE to search for all related CF34 events, from either development or revenue service experience. GE summarized available data in that regard, but the service data available does not contain the detail available from the FTP testing.

Regards,

[redacted]

Paul R. Mingler
Commercial Flight Safety Director

CF34 "Core Lock"

Introduction

At the recent Pinnacle investigation team meetings in Montreal discussion of the CF34-3 engine event known as "core lock" resulted in a request by a representative of the NTSB for additional information. The questions posed were:

1. What is a "core lock" event?
2. What is the history of design changes directed at reducing core lock?
3. What is the flight test and in-service experience with core lock for engine shutdowns from high power in combination with the core rotational speed decaying to zero and a prolonged driftdown period?

This document is provided to address these inquiries.

Summary

Core Lock is understood to be caused by the contact of the HPT inter-stage seal (ISS) static honeycomb component with the rotating seal teeth on the Outer Torque Coupling resulting in a frictional sticking (stiction) that results in the rotor being temporarily inhibited from rotating.

Core lock, if encountered at production acceptance flight test (FTP), is eliminated by an in-flight break-in procedure referred to as a seal "grind-in".

Flight test experience has shown that air turbine starter (ATS) starter torque is capable of overcoming the ISS stiction that results in core lock.

What is a "core lock" event?

The engine core hardware heats up during high power operation. There is radial and axial growth in the turbine static and rotating parts. Because the static parts have a lower mass and more direct exposure to flowpath air, the thermal time constant for growth of the stator hardware is faster than that of the rotating parts (rotors and inter-stage seal (ISS)) and initially the stator grows away from the rotor. Over the course of a Takeoff and Climb to cruise altitude, the rotating and static hardware reach an equilibrium condition and the labyrinth seals wear a track in the stationary seal. Under normal engine operating conditions, there is sufficient clearance between the core rotor and the stator such that the core rotor is free to turn. When the engine is shutdown at altitude, the core begins to cool and the stator, including the static ISS, contracts at a faster rate than the adjacent rotating parts in both the radial and axial direction because of its faster thermal time constant. The relative rate of cooling of the stator and rotor results in an alignment of the rotating seal knife-edges aft of the normal operating groove in the static seal. If the clearances are tight enough and the relative cooling rates are right, contact can occur between the static and rotating seal elements. The resulting stiction can temporarily prevent the rotor from turning when only the force of ram air is applied to the core. Air turbine starter (ATS) torque has been shown adequate to overcome this stiction.

What is the history of design changes directed at reducing core lock?

Core lock has been experienced on new engines at production acceptance flight test throughout the CF34-3 program. Attempts have been made to reduce the occurrence of core lock by a more rigorous Sea Level factory test cell break-in procedure. However, it was determined that the sea level environment does not break-in the seal in the axial location encountered in flight. As a consequence, a procedure to check all engines during production aircraft acceptance flight test was implemented and has been performed on all CF34-3A1 and CF34-3B/3B1 engines. The procedure is as follows: (a) climb to FL310, (b) retard the throttle to Idle and stabilize for 5 minutes, (c) shutdown the test engine, (d) drift-down at 190 kias, (e) slow the aircraft until core rotational speed is reduced to zero, (f) at 8 ½ minutes push-over to 320 kias (a windmill starting airspeed) and (g) ensure engine rotation is achieved. If an engine does not rotate with the ram force of a windmill (W/M) start, an air turbine starter (ATS) start is performed and the aircraft is flown back up to FL310. The procedure above is repeated, but this time driftdown airspeed is maintained sufficiently high (~240 kias) so as to keep the core rotating at 4% N2. This "grind in" procedure wears in the seals at the more aft axial location encountered during windmill operation. The windmill start procedure is then repeated to confirm the core is free to rotate. To our knowledge, no engine has exhibited core lock subsequent to the aircraft acceptance process (FTP). Further, the ATS starter has successfully rotated all engines that have experienced core lock. The above procedure had been performed on A/C 7396's LHE ESN 872746.

Design changes have been implemented in an effort to reduce the rate of occurrence of core lock. In 1992 the OBP seal grind was changed from a 4 step to an 8 step configuration. The intent of this change was to increase the clearances on the static seal, aft of the normal operating groove while leaving normal running clearances unchanged. This change did not measurably impact the rate of occurrence. Also, the grind dimension of the ISS was increased for the CF34-3A1 engine model in 1994 to open the clearance an additional 2 mils.

The CF34-3B1 ISS clearance was set at the same dimension as the CF34-3A1. The ISS grind dimension was validated by processing the first 10 months of production engines (approximately 40 engines) through aircraft production acceptance flight test and trending core lock frequency. The core lock experience was deemed equivalent to the –3A1 engines. The ISS clearances were opened on a trial basis 3 times over the course of the CF34-3B1 program to assess the performance impact. The nominal production clearances have remained unchanged. Finally, the CF34-3B1 HPTS stage 2 nozzle support gap was reduced by 0.005”. Since the static ISS mounts off the stage 2 nozzle, this change was expected to equate to a 0.003” more open ISS clearance during windmill start conditions. This is the current engine configuration.

A sample of 669 engines tested between March 2001 and September 2004 showed 27 engines required the grind in procedure to correct core lock. Currently the rate of occurrence, as represented by the last 200 engines in the sample, is about 1.5%. Figure 1, attached, presents the --- --------------------

What is the flight test experience with “Hot Engine” shutdowns?

A review of the data at General Electric found 6 cases of flight test data where the engine was shutdown directly from high power, or with only a short period of time (37 to 80 seconds) at Idle prior to shutdown, followed by a lengthy drift-down period. In these 6 cases the core rotated with either windmill ram force or ATS assist if the aircraft was not accelerated to windmill airspeed. Additionally, 2 test points are included where the pre-shutdown conditions are not known. These points were flown on A/C 7002 with engines 807003 and 807004. They have been included because the point flown on engine 807004 did not rotate 15 minutes after shutdown, at ram airspeeds up to 356 kias. No ATS start was attempted but twenty-four minutes after shutdown the engine core did rotate with only windmill ram air force at 255 kias. The GE records indicate this may have been the first time that ESN 807004 was shutdown at high altitude and performed a long duration spooldown to N2=0 before restarting. A search of the Bombardier records would be required to confirm the history. Engine 807004 was built prior to any design revisions directed at alleviating core lock. The LHE, 807003, did rotate with only windmill ram force.

Attached table 1 summarizes --- --- --

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A more extensive sample of other flight test engine restart test points exists following one of two procedures: 1. the procedure followed is: (a) the engine is operated at high power, (b) the throttle is stabilized at Idle for 2 minutes, (c) the engine is shutdown, (d) the aircraft drifts down at 190 kias for 15 minutes with N2 decreasing to zero, (f) the aircraft pushes over to 300 kias and (g) a windmill start is performed and
2. the procedure is: (a) Stabilize at high power, (b) shutdown the engine, (c) drift down for 2 minutes and (d) perform a windmill or ATS restart.
Procedure 1 above was defined for flight test to create an extreme cold engine starting scenario. Procedure 2 was developed as an extreme hot engine restart test.

No core lock is known to have occurred on any of these start attempts

What is the in-service experience with "Hot Engine" shutdowns?

A review of field events yielded 1 event with a shutdown from high power followed by a long drift down period and with N2=0 during the drift down. Aircraft 7210 was in straight and level flight at FL350 , airspeed=247 kias operating at 94.4% N1 when the LHE experienced a flameout. The engine had been at high power for about 50 minutes. The core rotation wound down to 0 rpm. Nineteen minutes after shutdown the aircraft was accelerated to 311 kias and the engine core speed increased, eventually achieving 12.6%.

No other applicable events have been identified.

Attached table 2 summarizes --

ATTACHMENTS WITHDRAWN